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EFFECTS OF VARIOUS GASES ON HANDGEAR INSULATION

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The following corrections apply to Technical Report No. AMRL-TR-65-4, Effects of Various Gases on Handgear Insulation.

Page iii (Abstract) & DD Form 1473 (Abstract)

Eleventh line: change "(5 cm water)" to read "(7.6 mm water)"

Page 2

Paragraph 1, line 5: change "260 mm Hg" to read "130 mm Hg"

Paragraph 1, line 7: change "(i.e., 76 mm H_2O)." to read "(i.e., 7.6 mm H_2O)."

Page 4

Figure 2, title: change "260 mm Hg" to read "130 mm Hg"

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FOREWORD

This study was performed by the Biomedical Laboratory, Aerospace Medica Research Laboratories, Wright-Patterson Air Force Base, Ohio. This report summarizes one aspect of the internal research programs being conducted by th Biothermal Branch, Physiology Division of the Biomedical Laboratory, under Project No. 7164, "Biomedical Criteria for Aerospace Flight," Task No. 71640 "Human Thermal Stress." The work was begun in September 1964 and complete in March 1965.

This technical report has been reviewed and is approved.

WAYNE H. McCANDLESS
Technical Director
Biomedical Laboratory
Aerospace Medical Research Laborat

ABSTRACT

The effect of gases having different thermal conductivities on the thermal insulation of handgear was investigated. Experimental mittens with special plastic spacer interliners of various thicknesses were sealed between gas impermeable outer and inner shells and filled first with room air (as control), then various experimental gases, and thermal insulation measured on a copper hand. Experimental gases included carbon dioxide, Freon-12, and helium. Comparative results are presented in terms of percentage insulation change; clo per inch; conductivity (K) values; and the measured thermal insulation (clo) values. Before all tests each mitten was evacuated (13 cm Hg) to remove all entrapped air, then filled without contamination with the control, or experimental gas. Gas within the handgear was maintained at a constant positive pressure (5 cm water) throughout each experiment. Mean measurements showed significant increases (13-32%) of thermal insulation for Freon-12 and carbon dioxide, with decreased insulation observed with helium. Significance and some practical application of these results for protective clothing design are shown.

INTRODUCTION

Thermal protection of the hands during cold exposure is a difficult and commonly acknowledged problem. The theoretical limitations involving shape and practical maximum limits of thickness consistent with manual dexterity were carefully and extensively outlined by van Dilla, Day and Siple (ref. 2). The superiority of mittens to gloves with respect to both insulation and efficiency of fabric use was demonstrated by Washburn et al (ref. 6) as early as 1944. Significant improvement of handgear insulation since this date has not been achieved. However, in 1955 Hammel (ref. 5), using a guarded hot plate technique in an investigation of the thermal properties of furs, measured marked increases (4x) of insulation when Freon-12, a gas of relatively low thermal conductivity, was tested. Application of this observation as a potential means of improving handgear insulation thus appeared possible. The experiments reported were performed to determine the effects of several gases, including Freon-12, having different thermal conductivities on handgear (mitten) insulation as measured with a thermal (copper) hand. Physical properties of these gases (refs. 1, 4) are shown in Table I.

TABLE 1

PHYSICAL PROPERTIES OF EXPERIMENTAL GASES

Gas	Density 0°C, 760 mm Hg g/liter	Thermal Conductivity k_t cal cm/sec cm^2 °C
1. Air	1.292	5.66×10^{-5}
2. Carbon Dioxide, CO_2	1.976	3.32×10^{-5}
3. Freon-12, CCl_2F_2	5.083	2.10×10^{-5}
4. Helium, He	0.178	34.4×10^{-5}

SECTION II

PROCEDURE

Figure 1 shows the thermal (copper) hand, recording potentiometer, wattmeter, and general arrangement of experimental gas cylinder, syringe for evacuation and filling, and pressure gauges. Procedures for using the experimental gases, and a cross-section drawing of the mitten construction are shown in figures 2 and 3. The mitten was evacuated to 260 mm Hg negative pressure before it was filled with the experimental gas and all tests were performed with handgear maintained at a slightly positive pressure (i.e., 76 mm H_2O). This was essential to prevent contamination by air if leakage should occur and to maintain a constant thickness. Thermal insulation measured in 7 experiments at 20-25 C and thermal equilibrium was calculated in clo units (ref. 3) using the following equation.

$$I_g = \frac{k(T_s - T_m)}{H_g}$$

where

I_g = thermal insulation of glove, or mitten (clo units)

k = constant, (3.09) converting to clo units

T_s = mean thermal hand surface temperature, °F

T_m = mean outer handgear surface temperature, °F

H_g = heat loss through handgear, Cals/M² hr $\frac{\text{watts} \times 0.86}{\text{Surface area } (M^2)}$

(.049 M² = Surface area hand used)

Since this equation includes the temperature gradient between copper hand surface and outer handgear surface, the need to consider effects of insulation of ambient air is eliminated. The Tri-lok interliner is a loosely woven plastic material used to provide maximum gas space with minimum conducting surface, yet of sufficient strength to resist reasonable compression loads.

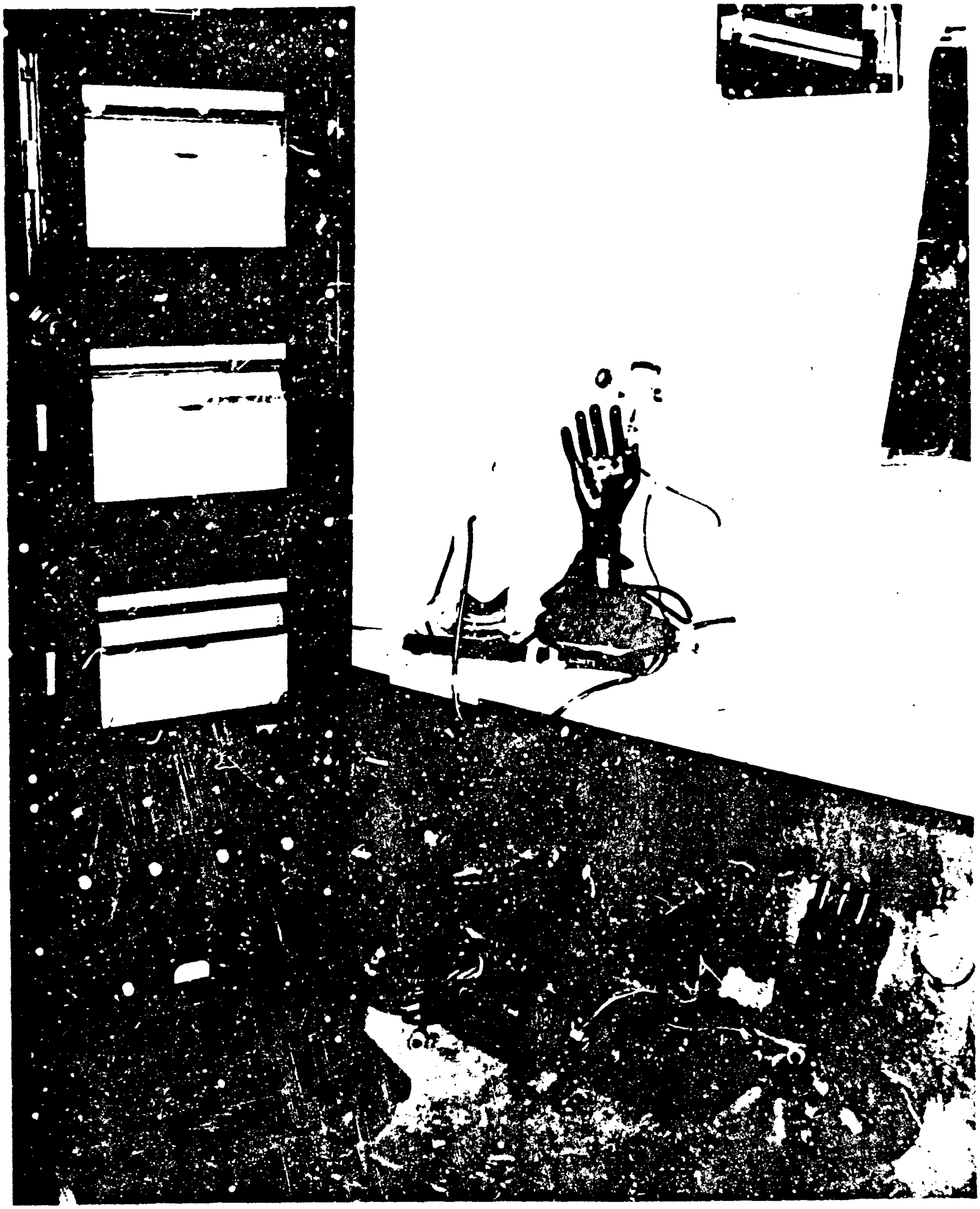


Figure 1. Exterior Photograph of Equipment.

PROCEDURE FOR USING EXPERIMENTAL GASES

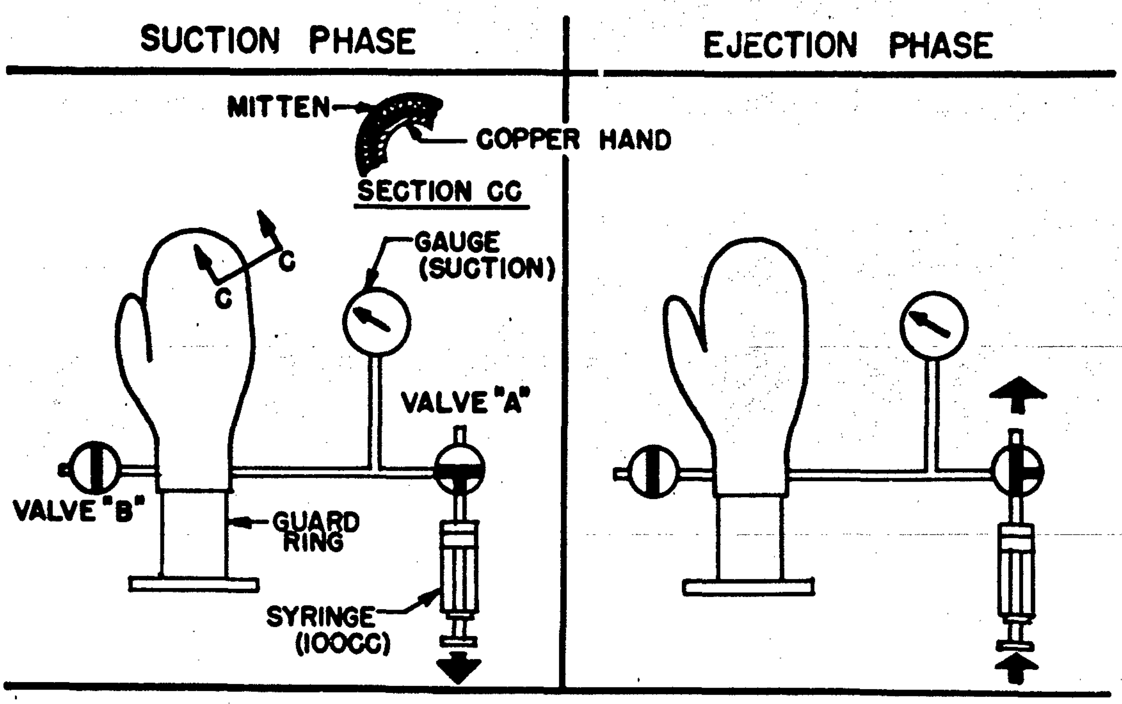
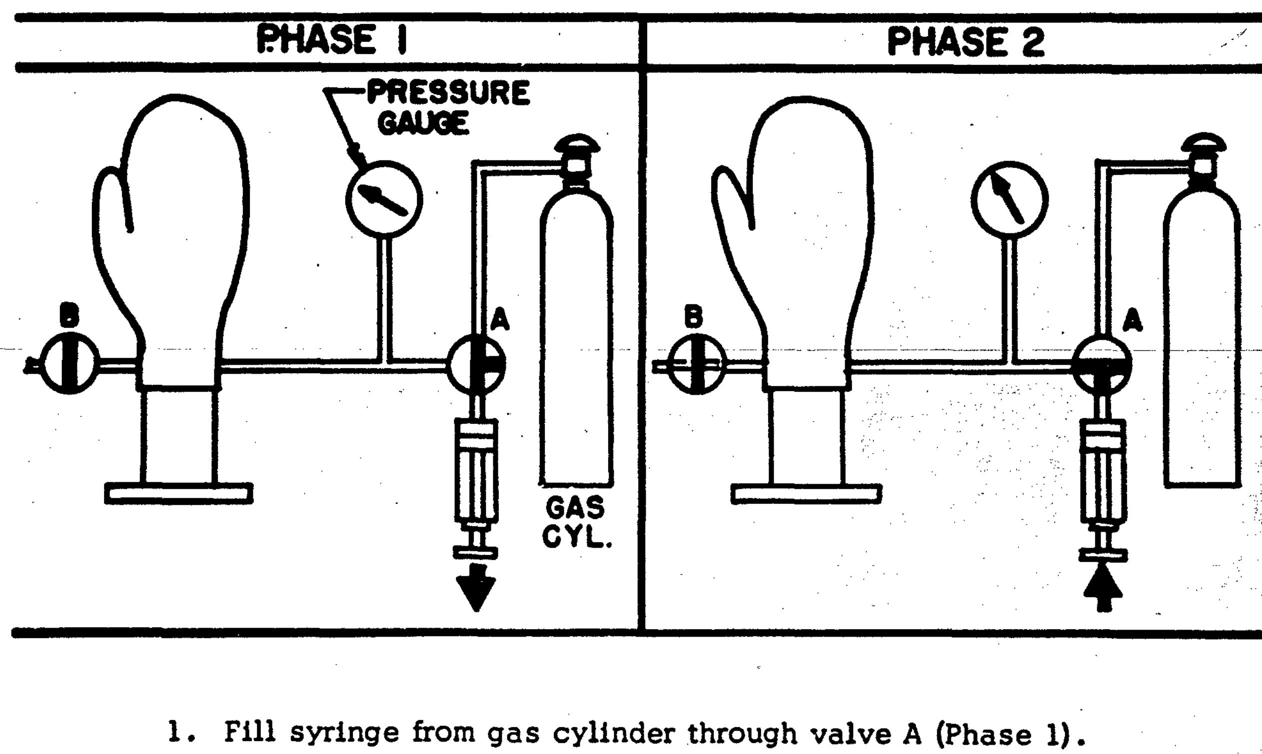


Figure 2. Evacuation of Mitten to 260 mm Hg Negative Pressure Using Syringe.



1. Fill syringe from gas cylinder through valve A (Phase 1).
2. Fill mitten from syringe (Phase 2).
3. After overfilling release pressure in mitten to 76 mm H_2O above atmospheric pressure using valve B.

Figure 3. Filling of Mitten.

RESULTS

The linear relationship between thickness and thermal insulation is shown by the curves in figure 4. Both mean and individual thermal insulation (clo) values for the room air control and the experimental gases at the respective handgear thicknesses are shown. These values were 1.02, 1.07, 1.21, and 0.60 for air, CO_2, Freon-12, and helium, respectively, as measured with mitten I at 0.37 cm total thickness. These values increased to 1.17, 1.31, 1.47, and 0.83 at 0.69 cm thickness (mitten II) and to 1.50, 1.60, 1.70, and 0.97 at the 1.00 cm thickness (mitten III). The method used yields precise, reproducible values with standard deviations ranging from ±0.01 to 0.08, and standard errors from ±0.003 to 0.019. Difference between the interliner and total thickness as shown by arrows represent thickness of the outer and inner gas impermeable layers.

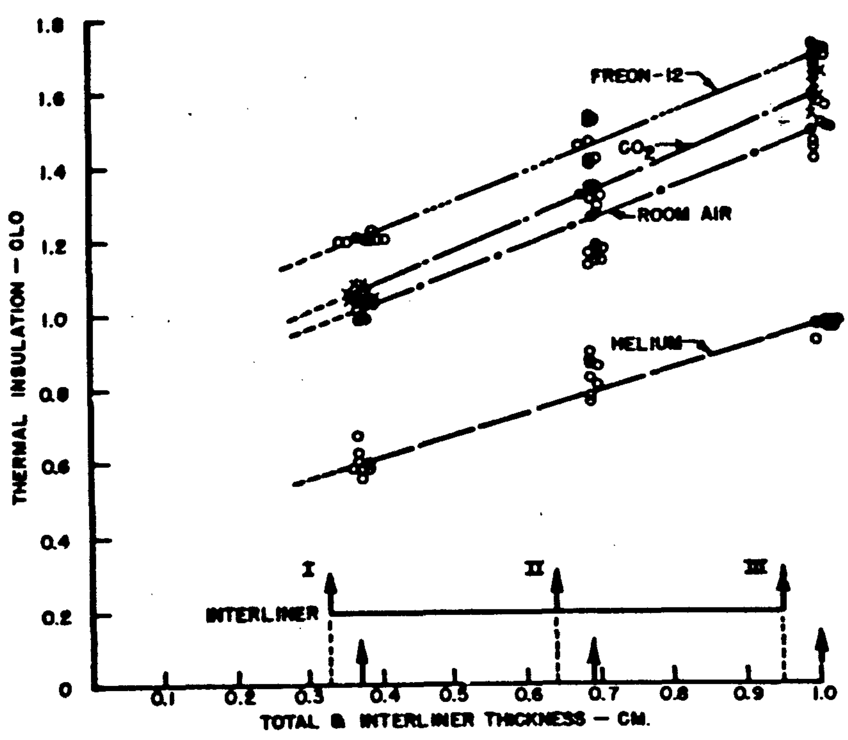


Figure 4. Thermal Insulation of Gases at Various Mitten Thicknesses.

TABLE II - EXPERIMENTAL DATA SUMMARY

Handgear No.	Interliner Type	Interliner Thickness cm	Gas	Mitten Surface Area M^2	in.	cm	Mean Thermal Insulation (I_m) No. of Tests	Clo	SD	SE	Clo/in	Difference from air %	Thermal Conductivity K*
Mitten I	Tri-lok	0.32	Room air	0.083	0.145	0.37	7	1.02	±.02	±.006	7.01	-	1.19
	"	"	CO_2	"	"	"	"	1.07	±.02	±.006	7.21	+ 4.9	1.14
	"	"	Freon-12	"	"	"	"	1.21	±.01	±.003	8.34	+18.6	1.00
	"	"	Helium	"	"	"	"	0.60	±.03	±.007	4.17	-41.2	2.01
Mitten II	Tri-lok	0.64	Room air	0.088	0.270	0.69	7	1.17	±.02	±.006	4.32	-	1.82
	"	"	CO_2	"	"	"	"	1.31	±.04	±.011	4.87	+12.0	1.62
	"	"	Freon-12	"	"	"	"	1.47	±.06	±.016	5.45	+25.7	1.44
	"	"	Helium	"	"	"	"	0.83	±.05	±.013	3.10	-29.1	2.54
Mitten III	Tri-lok	0.95	Room air	0.094	0.395	1.00	8	1.50	±.08	±.019	3.80	-	1.94
	"	"	CO_2	"	"	"	7	1.60	±.04	±.011	4.05	+ 6.7	1.81
	"	"	Freon-12	"	"	"	7	1.70	±.02	±.006	4.31	+13.3	1.70
	"	"	Helium	"	"	"	6	0.97	±.02	±.006	2.45	-35.3	3.00

*Thermal Conductivity (K) $= \frac{Q}{A} \times \frac{d}{\Delta T°C}$

Q = Cals/hr (heat input)
A = Outer surface area of mitten, M^2
d = Thickness of mitten, centimeters
ΔT = Temperature difference between copper hand surface + outer mitten surface, °C

Table II presents the measured mean thermal insulation values, the calculated percentage differences from air, and calculated thermal conductivity (K) values for these gas-filled handgear models. These conductivity values vary from those of the pure gas, since they include the conducting outer and inner handgear layers as well as the plastic interliner. Comparative handgear insulation measured at equivalent total thickness with the various gases is presented in figure 5. The marked difference between the measured insulation with helium as compared with the other gases is due presumably to the relatively high thermal conductivity of helium. This gas was used in our experimental program chiefly to provide a broad range in relative thermal conductivities and also to validate to some extent the experimental technique and insulation test method used. The general increase in absolute insulation (clo unit) with thickness is clear even with helium, and the thermal insulation values measured at 1.0 cm probably represent the upper practical limit of mitten thickness consistent with an acceptable degree of manual dexterity.

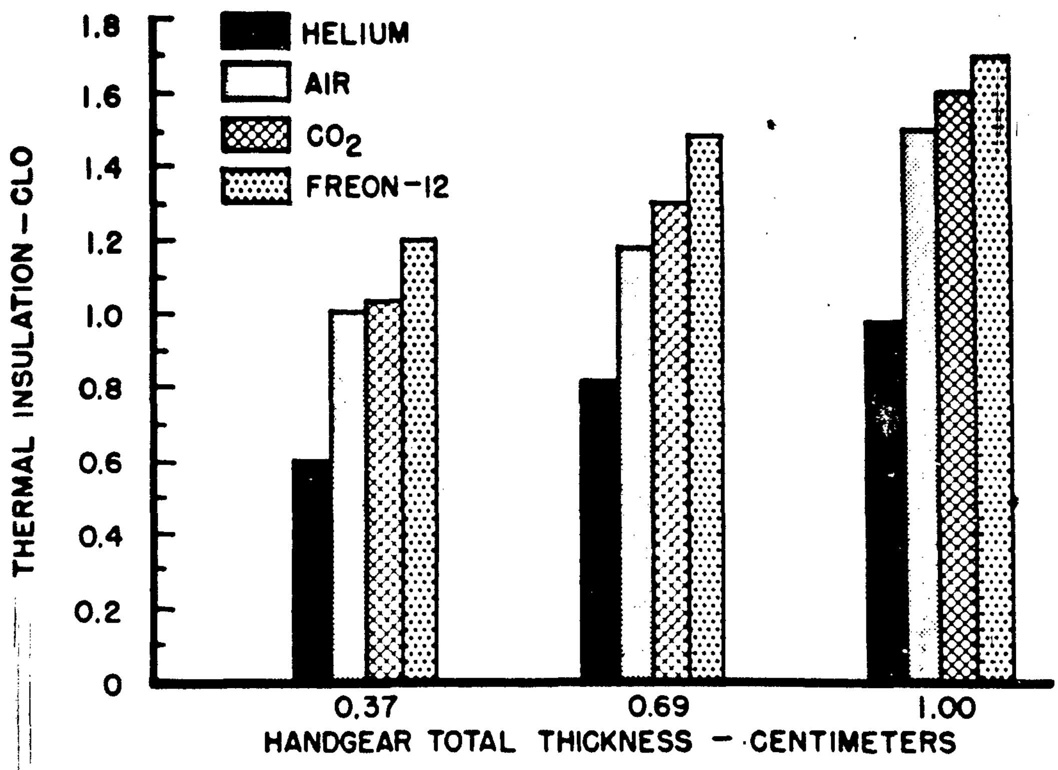


Figure 5. Comparative Thermal Insulation of Gas-Filled Mittens.

However, in terms of the maximum percentage increase of insulation with thickness, the results, shown in figure 6, indicated the 0.69 cm thickness to be optimal. This was confirmed by the measurement with helium also where percentage reduction of insulation was least at the same thickness. In figure 7 the relationship between the theoretical thermal conductivity of the respective gases and the measured mean thermal insulation are shown as curvilinear. The individual curves represent the various handgear thicknesses used. For significant increases in handgear insulation (clo) gases with thermal conductivity lower than air must be used.

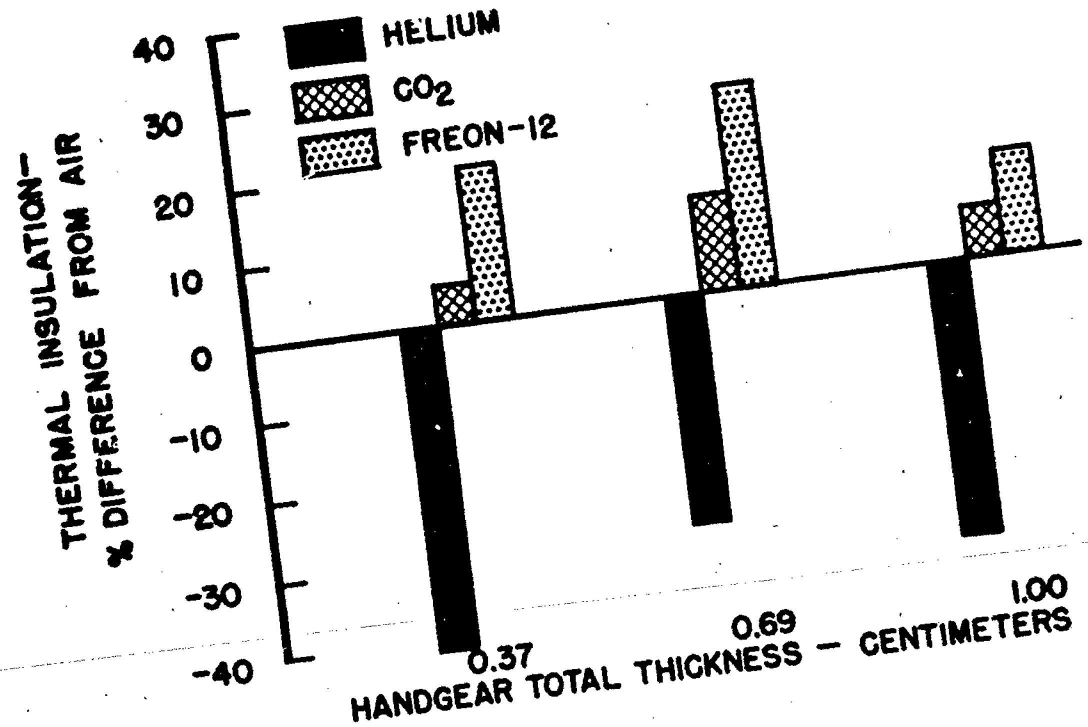


Figure 6. Relative Changes in Thermal Insulation with Various Experimental Gases.

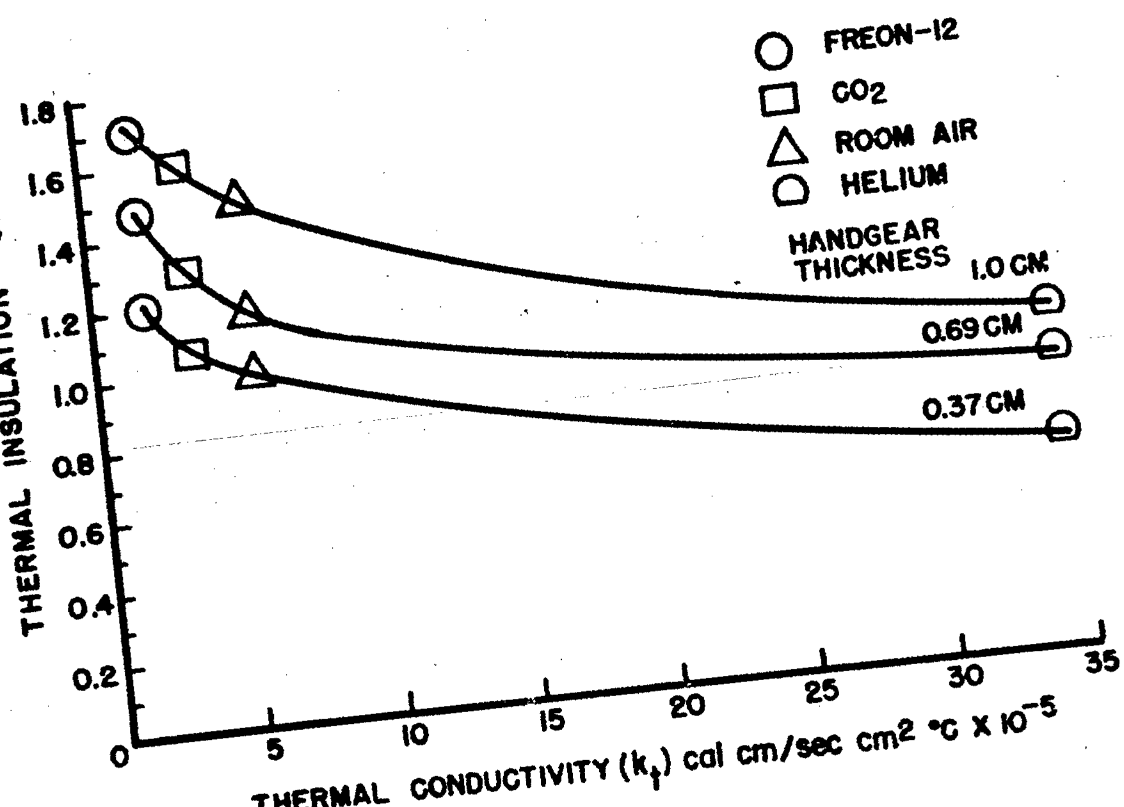


Figure 7. Relationship of Thermal Conductivity and Insulation in Gas-Filled Handgear.

DISCUSSION

The relationship between the mitten thickness and thermal insulation using these experimental gases was linear, as anticipated. We were unable to have glove-fingers fabricated in the desired thickness range that would fit between the fingers of our thermal (copper) hands; therefore, we could not use gloves to obtain these measurements. However, it is reasonable to assume that generally similar relationships would be observed, although at lower thermal insulation values because of the shape factor involved.

The results confirmed Hammel's observation* that both Freon-12 and CO_2 increase thermal insulation. However, for mitten-type handgear the magnitude of this increase is markedly less (27%) than that observed with furs (400%) when plane surfaces and a guarded hot plate technique were used. These differences probably result from different shape factors; the smaller practical limits of handgear thickness; our requirement to use impermeable outer and inner shells to retain the gases used; and the presence, even though of minimal mass, of the woven plastic interliner which acts as a heat conductor. Because of liquefaction problems with Freon-12 at low ambient temperatures and in view of the lower cost (one-third per 28.3 l) of carbon dioxide, the latter may be considered as potentially the best gas for practical applications. While some increase of thermal insulation values at low temperatures may be predicted with the experimental gases, the relative gain (in clo units) over that achieved with air-filled handgear would be insignificant. Other types of gases (Freon-13 rather than Freon-12, or Xenon) are being considered for improving various types of protective clothing. The techniques and gases used in this handgear test program are now being extended to experimental footgear. For footgear a much wider thickness range (1.0-2.5 cm) is being investigated with a thermal (copper) foot. In these tests percentage increases of insulation more nearly approaching those reported by Hammel may be observed. However, both the shape factor and the necessity of using conducting fabric layers and interliners will act as limiting variables in the thermal insulation measured. If indicated by the physical model test data, validation programs at low ambient temperatures with human extremity cooling techniques may be used. The principle of gas insulation is obviously best applied to clothing systems free from, or highly resistant to, compression loads.

In summary, the experimental data show: (a) significant percentage increases of handgear thermal insulation can be achieved by using gases with low thermal conductivity; (b) optimal and practical thickness for mitten-type handgear is relatively low (0.69 cm); and (c) significant decreases of insulation are observed with helium. This gas as a heat removal vehicle in forced convected aerospace protective systems may prove useful.

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*From a study by H.T. Hammel, D.R. Griffin, H.M. Johnson, and K.S. Rawson entitled The Comparative Physiology of Thermal Insulation, done under Contract AF 33(038)-12764, with Arctic Aeromedical Laboratory, Alaska, in July 1953.

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13. ABSTRACT

The effect of gases having different thermal conductivities on the thermal insulation of handgear was investigated. Experimental mittens with special plastic spacer interliners of various thicknesses were sealed between gas impermeable outer and inner shells and filled first with room air (as control), then various experimental gases, and thermal insulation measured on a copper hand. Experimental gases included carbon dioxide, Freon-12, and helium. Comparative results are presented in terms of percentage insulation change; clo per inch; conductivity (K) values; and the measured thermal insulation (clo) values. Before all tests each mitten was evacuated (13 cm Hg) to remove all entrapped air, then filled without contamination with the control, or experimental gas. Gas within the handgear was maintained at a constant positive pressure (5 cm water) throughout each experiment. Mean measurements showed significant increases (13-32%) of thermal insulation for Freon-12 and carbon dioxide, with decreased insulation observed with helium. Significance and some practical application of these results for protective clothing design are shown.

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